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Final Technical Report

on Contract Nonr 233(96)

ATMOSPHERIC TRANSMISSION OF LASER BEAMS

Project Director: Professor Zdenek Sekera

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ABSTRACT

After a thorough survey of the existing literature and experimental facilities available in the area, the program of investigations leading to the study of atmospheric limitations to the propagation of laser beams have been outlined. Realization of this program has been prevented by the lack of further support.

This report contains the results of the investigations carried out under a Contract No. Nonr 233(96) on the atmospheric limitations to the propagation of laser beams. The contract was received in March 1965 for the first year's work.

Since the achievement of laser action in pink ruby by Maiman in 1960, a large number of coherent, monochromatic sources of radiation spanning the electromagnetic spectrum from about .5μ to 35μ have come to practical use for various applications. The successful demonstration of Raman laser action in many substances has opened up the possibility of making useful additions to the number of coherent lines obtained directly by laser action.

The transmission of laser beams through the earth's atmosphere, the interplanetary medium and the atmosphere of other planets have assumed immediate significance in connection with the potential use of lasers in the field of communications. The transmission problem is of equal interest in the atmospheric sciences where the prospect of using laser radars as probes offers unique advantages. Several meteorological applications of such radars as, for example, in the detection of clear air turbulence and the location of inversion and dust layers both at low and high levels in the atmosphere have been suggested and in some cases successfully demonstrated.

Extensive investigations on the effectiveness of laser beams for communication purposes have brought to the surface several interesting and intriguing problems which require detailed considerations. Since the problem becomes quite complicated if one has to take into account all the factors contributing to the

limitations of laser beam propagation in the atmosphere, it is necessary at least in the preliminary stages to consider them separately.

The problems of direct concern to this investigation are those arising out of scattering. For an effective solution of these problems, the method of radiative transfer theory can be adopted taking into account non-linear effects, time dependent factors, resonance effects, etc.

The light from the laser sources operating in the infrared region will interact most effectively with scatterers whose dimensions are in the micron and sub-micron range and are present in the earth's atmosphere (and presumably in other planetary atmospheres) as aerosols, meteoric matter and other suspensoids. The scattering process is described by Mie theory. The high intensities available from laser beams make it necessary to consider non-linear interaction terms which are usually neglected when scattering of ordinary light is considered. The effect of non-linear interaction terms will make the phase matrix more complicated.

When dealing with high power pulsed laser beam propagation through the atmosphere which is an inhomogeneous and turbulent medium it may be necessary to take into account the secondary sources generated in the medium and also time dependent parameters in radiative transfer equations.

Certain frequencies of operation of the laser beams might be placed close enough to rotational or vibrational rotational frequencies of molecules present in planetary atmospheres. In such cases resonant absorption and/or scattering might occur. Study of such absorption or scattering or both can lead to the detection

and, in favorable cases, the determination of height distribution of the molecules concerned.

The effect of multiple scattering of laser radiation in clouds is to give on the detector system a mean power level which is independent of the random motions of the particles and a very small fluctuating power level which depends on the random motions of the particles. A proper design of the detector geometry will depend upon the multiple scattering paremeters.

As the first phase of the research under the contract, Dr. Hariharan got acquainted with the voluminous literature available on lasers and their applications. In order to locate a proper operating laser system which could be used for further work, he visited several laboratories on the campus and in the vicinity. He visited Michelson Laboratory at NOTS at China Lake, where a generous collaboration was promised. Moreover, he participated at the Conference on Atmospheric Limitation to Optical Propagation, held by the National Bureau of Standards and National Center for Atmospheric Research in Boulder, Colorado, March 18-19, 1965.

After the literature survey and the survey of eventually available laser systems for experimental work, Dr. Hariharan spent a considerable amount of time in discussing with the project director the experimental program which would be in the realm of the available funds. Hence a simple design was conceived, first for a laboratory, then after a slight modification, for field work as well.

This system was proposed to have the following characteristics. The output beam of a laser source (either continuous or pulsed) will be spread over a large area of cross section by means of a diverging lens and an off axis parabolic mirror. Particular care will be taken to have as uniform an irradiance across the beam area as possible. The expected variation in irradiance will be less than 5 per cent. The expanded beam will pass through a large chamber wherein fogs of different optical thicknesses or particles of different sizes can be generated artifically with an ultrasonic nebuliser or aerosol generator. The laser beam passing through the chamber will suffer multiple scattering. The beam will be collected by an optical system onto a detector. The signal received by the detector will consist of two parts: (a) a steady signal due to the direct radiation; and (b) a fluctuating signal arising due to multiply scattered radiation whose angle of scattering can assume various values for different particles in the medium. It is possible to limit the angle of scattering for the scattered radiation entering the dectector system by proper arrangement of field stops in the optical set up. The detector to be used will be a photomultiplier tube with an S-20 spectral response having high sensitivity and very low dark current. The output signal of the photomultiplier tube will be analysed by electronic devices to separate the steady and fluctuating components.

The main difficulty encountered in the experimental set up is the ability to achieve uniformity of irradiance over the beam cross section within reasonable limits. As is well known the intensity distribution across the area of the beam

coming out of a laser is Gaussian. If this is further spread out over a large area using an off axis parabolic mirror the irradiance becomes quite nonuniform. The necessary corrections have to be applied through what may be called uniformity masks containing neutral density coatings with varying transmissions across the surface.

The following experiments have been planned with the set up described above.

1. To study the effect of varying optical thickness of the medium on the scattered signal received.
2. To study the effect of varying particle sizes on the scattered signal.
3. To study the dispersion with wavelength of the above two phenomena using different lasers.
4. To compare the effects due to a coherent laser source and an incoherent source such as a high intensity Xenon or Mercury arc.
5. To study the amount of energy appearing in the wavelength region beyond the narrow halfwidth of the laser beam. This may give an idea of the amount of energy converted as Stokes or Antistokes radiation arising due to rotational or vibrational Raman scattering by the molecules in the medium.
6. To study the resonant bsorption and/or scattering by water vapor of $\lambda = 1.153\mu$ radiation of He-Ne laser.

The experiments described above were planned to be carried out during the period January 1966 - December 1967. The contract was extended without

additional funds to April 1966 to allow closing out of activities. However the contract was not renewed and thus further work along the lines described above was stopped and was not realized.

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